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Climate adaptation indicators and metrics: State of local policy practice

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ABSTRACT

Recent systematic reviews show that, overall, and across governance levels and sectors, climate change adaptation monitoring and evaluation (M&E) systems are rarely programmed and implemented. As a result, there is a generalized lack of knowledge and practice regarding the definition and use of adaptation indicators and metrics from which to effectively learn. This paper focuses on understanding the emergent state of practice regarding adaptation indicators and metrics at the local level: what indicators and metrics are used? What aspects of the adaptation process are they measuring? How will they be monitored, evaluated, and reported? Out of a sample of the largest 136 coastal cities worldwide, only 59 cities have adaptation-related plans and only 11 (Athens, Auckland, Barcelona, Glasgow, Lima, Montreal, Nagoya, New York City, Portland, Tokyo, and Vancouver) list indicators and metrics. Sourced from these documents, we compile and code a total of 1971 indicators, of which 1841 focus fully or partially on adaptation-related aspects. We study the level of detail (objective, indicator, metric), type (target, input, output, outcome, or impact), scale, dimension, units of measurement, target, and proposed monitoring timeframe, among other aspects. Data shows that current adaptation measurement frameworks are tied to the degree to which each city integrates and addresses adaptation in its policies. A majority of adaptation indicators and metrics measure outputs, i.e. implementation aspects. Outcome indicators are generally connected to users or beneficiaries of adaptation measures and impact indicators are mostly related to health (e.g. hospitalizations). Targets and monitoring timeframes, as well as data sources, are rarely defined. We connect this to a lack of definition of local adaptation goals and a poor understanding of how specific adaptation actions lead to vulnerability reductions and resilience increases. Based on the identified gaps, we propose a metric development guiding framework to stimulate discussion around effective and feasible approaches to measure adaptation progress based on improved adaptation decision-making. We argue, that our results should fuel a critical revision of current adaptation planning practices that might ultimately facilitate processes of learning, experimentation and innovation in this embryonic field.

1. Introduction

Measuring climate change adaptation progress is paramount to properly understanding changing vulnerabilities, in addition to showing how adaptation policies, strategies, and initiatives influence these vulnerabilities (Arnott et al., 2016; Ford et al., 2015; Magnan, 2016; Singh et al., 2021). Not only does adaptation measurement help to understand the potential positive effects of adaptation, but also, the negative consequences of inadequate interventions that have not accounted for the potential redistribution of vulnerabilities or negative impacts on sustainability (Eriksen et al., 2021; Magnan et al., 2016). Implementing monitoring and evaluation frameworks also increases the public's awareness of these plans, along with increasing the cost awareness of adaptation, which in turn allows for a better distribution of resources (Adaptation Committee, 2021; Tompkins et al., 2018).

However, several challenges afflict these mechanisms. Conceptually, there is a lack of consensus on what constitutes successful (or effective) adaptation (Adaptation Committee, 2021; Dilling et al., 2019; Ford et al., 2015; Moser & Boykoff, 2013; Singh et al., 2021; Tompkins et al., 2018). This relates to how to establish boundaries about what is and what is not adaptation (Singh et al., 2021) and limitations resulting from the inability to validate adaptation outcomes when impacts have not

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happened yet (Ford et al., 2015; Ford & Berrang-Ford, 2015; Olazabal et al., 2019a). As a consequence, establishing what needs to be measured and who is responsible for its measurement turns complicated. Adding to this, it is argued that adaptation assessments are incapable of being completely objective as a result of value judgements being present in the assessment of adaptation actions (Leiter & Pringle, 2018). Furthermore, adaptation has to grapple with the analytical challenge of whether changes are due to adaptation initiatives or other factors conditioning behaviour (Pearce-Higgins et al., 2022). Empirically, uncertainty and a lack of data associated with difficulties in the operationalization, access, synthesis, and reporting of data represent the main challenges faced by adaptation metrics (Adaptation Committee, 2021; Dilling et al., 2019; Mutimba et al., 2019). Adding to this, if structural inequalities are not taken into consideration during the design process, these frameworks run the risk of increasing them and reinforcing power asymmetries amongst communities (Adaptation Committee, 2021; Coger et al., 2021; Dilling et al., 2019; Hughes et al., 2020; Solecki & Rosenzweig, 2020).

All this has resulted in scattered approaches and diversification of methods to overcome these challenges. At the national level, for example, countries like Brazil and St. Lucia use questionnaires and information collection cards, while Norway uses an informal knowledge exchange system (Adaptation Committee, 2021). While part of the scientific community proposes sophisticated methods such as cost-benefit and cost-effectiveness analyses to assess adaptation effectiveness (Michaelowa & Stadelmann, 2018b) or adaptation pathways approach to monitor adaptation outcomes (Haasnoot et al., 2018), the most popular approaches to measure the progress of adaptation across any private or public governance scale are indicator-based systems. The United Nations Framework Convention on Climate Change (UNFCCC) reports indicators being used at the national level, for example, in Cambodia, Canada, Germany, Morocco, Mozambique and the UK (Adaptation Committee, 2021). At the sub-national level, global city networks encourage the use of indicator frameworks to assess adaptation progress (see, e.g., C40, 2019). Likewise, more recently, the newly established Race to Resilience (R2R) campaign (UNFCCC, 2021) is gathering proposals for adaptation metrics across joining initiatives in order to monitor the progress towards their overall goal of building the resilience of 4 billion people by 2030.

However, the use of indicator-based systems is not without its shortcomings. In general, indicators need to be precise, robust, transparent, objective, simple, and easy to understand, and they should be linked to appropriate datasets (Harley et al., 2008), i.e. measurement means. In the context of adaptation, Klostermann et al. (2018) propose the use of SMART criteria, i.e. making indicators specific, measurable, realistic, and time-related. While there is still debate on the advantages and disadvantages of the use of universal indicators or metrics for the measurement of adaptation (Michaelowa & Stadelmann, 2018a), generally, their interpretation will always be subjective to the viewpoint of the interpreter. In this sense, aspects of power, interests at stake, and the spatial and temporal scales used in the assessment can influence the use of information collected from the indicator in subsequent evaluation and learning stages (Hughes et al., 2020). As a consequence, the risk of marginalizing knowledge, ideas, and communities if indicators are not conceived, implemented, and evaluated properly emerges (Adaptation Committee, 2021; Coger et al., 2021; Leiter & Pringle, 2018; Olhoff et al., 2018; Schneiderbauer et al., 2013).

In general, most of the research on the topic of adaptation M&E at all levels has focused on the theoretical understanding of measurement processes and tools (e.g., Hale et al., 2021; Hallegatte & Engle, 2019), or on the empirical understanding of M&E related practices (Leiter, 2021; Olazabal & Ruiz De Gopegui, 2021) with little specific attention to real-world practice on adaptation indicators and metrics as tools to measure progress. This paper aims to fill part of this gap by looking at the practices of local public administrations from a sample of global cities. An analysis of the local level offers an opportunity to complement emergent efforts in depicting the landscape of monitoring and evaluation practices (Arnott et al., 2016; Olazabal & Ruiz De Gopegui, 2021; Scott & Moloney, 2022; Solecki & Rosenzweig, 2020) and provides a first glance at the state of practice in the definition of adaptation indicators and metrics that could be transferred to other levels of governance.

Here, we focus on publicly available city-level adaptation planning documents and show what types of indicators and metrics are used, how data is planned to be collected, and draw conclusions and policy recommendations based on identified gaps and needs. Our work is intended to serve as a first reference baseline of such local practice to fuel further studies that explore contextual factors and usability of such frameworks, as well as prospective studies that take stock of current initiatives to reflect on feasible higher-level adaptation stocktake mechanisms. Our intention is not to present best practices or classify certain plans as better than others. Rather, we intend to describe the who, what, when, from where, and how of the frameworks to identify needs and potential ways forward.

2. Data and methods

2.1. The sample of city-level adaptation plans

In a study of the global state of adaptation policy, Olazabal et al (2019) identified and analysed governmental adaptation-related public planning documents in the 136 largest coastal cities with over 1 M inhabitants, worldwide. Out of the total sample, the authors identified 57 cities and metropolitan areas plus 2 city-state areas with plans to adapt, either included in climate-focused plans or more general documents such as resilience or sustainability plans. In a subsequent study, Olazabal & Ruiz De Gopegui (2021) found that while 46 planning documents included a section to describe an M&E plan, only 13 claimed to have defined adaptation indicators. These cities were: Athens (Greece), Auckland (USA), Barcelona (Spain), Glasgow (UK), Istanbul (Turkey), Lima (Peru), Los Angeles (USA), Montreal (Canada), Nagoya (Japan), New York City (USA), Portland (USA), Tokyo (Japan) and Vancouver (Canada). This paper builds on this work to show the use and characteristics of adaptation indicators and metrics (referred to more broadly as indicators, hereafter) across climate adaptation-related planning documents in major cities around the world. We rely on these documents because of transparency and the commitment implied in publicly available documents, which make the adaptation policy process more credible (Olazabal et al., 2019a).

In a preliminary analysis of the 13 cities sample, neither Istanbul nor Los Angeles listed the indicators as part of their publicly available planning documents, thus, they were removed from the sample. The final list of cities, the name of the planning document assessed, and other relevant contextual information are shown in Table 1.

2.2. Data collection and analysis method

A sample of adaptation indicators listed in each governmental report was extracted[1] and a policy content analysis approach was used to extract relevant information regarding the proposed indicator-based system and characteristics for each indicator (see full methodological approach in Fig. 1). The data categories (see Fig. 1 and Table 2) have been selected following specialised literature in the field of adaptation monitoring and evaluation (e.g. Christiansen et al., 2018; Donatti et al., 2020; Feldmeyer et al., 2019; Hale et al., 2021; Hallegatte & Engle, 2019; Salehi et al., 2019; Solecki & Rosenzweig, 2020; Tyler et al., 2016). Data were both collected directly from the source documents and inferred by the team of analysts, as indicated in Fig. 1, and underwent a

[1] For documents written in Greek (Athens #1) and Japanese (Nagoya #7, Tokyo #10), Google Translate, complemented by DeepL translator and Jisho Japanese Dictionary, was used to translate into English and interpret the language.

Table 1
Sample of local adaptation planning documents and basic information. Notes: Type: A/M (adaptation and mitigation), A (adaptation only), R (resilience), E (environment), D (Development); Policy scale: M (metropolitan), C (city). Source: Olazabal and Ruiz de Gopegui (2021).

Id	City	Name of document	Year of publication	Type	Policy scale
1	Athens	Climate Action Plan Part B: Climate Adaptation Strategy: Making Athens a Greener and Cooler City	2017	A	C
2	Auckland	Auckland Plan 2050	2018	D	M
3	Barcelona	Plan Clima 2018–2030	2018	A/M	C
4	Glasgow	Our resilient Glasgow: A City Strategy	2016	R	M
5	Lima	Estrategia de Adaptación y Acciones de Mitigación de la Provincia de Lima al Cambio Climático-Estrategia C.Lima	2015	A	M
6	Montreal	Climate Change Adaptation Plan 2015–2020	2015	A	M
7	Nagoya	Low Carbon City Nagoya Strategy Second Execution Plan 2018–2030	2018	A/M	
8	New York City	OneNYC	2015	D	C
9	Portland	Climate Action Plan	2015	A/M	M
10	Tokyo	Tokyo Metropolitan Environmental Basic Plan (formulated March, Heisei 28)	2016	E	C
11	Vancouver	Vancouver Climate Change Adaptation Strategy	2018	A	C

deductive coding process.

Although expressed generally as 'indicators' or 'indicators and metrics', we here aim to stress the importance of identifying appropriate measurement approaches and categorize these by their "level of detail" referring to their degree of quantifiability (Arnott et al., 2016; Christiansen et al., 2018). The "level of detail" reflects how mature the evaluation system is and how close the monitoring provider could be to quantifying and measuring progress. We here innovatively use a 3-level classification, based on observed practice: Objective, Indicator, and Metric. An 'objective' points toward a goal and a tendency, but it is still ambiguous in identifying elements to assess (e.g. "increasing green infrastructure"). An 'indicator' refers to a particular element being assessed but does still not provide identifiable means of measurement (e.g. level of thermal comfort). A 'metric', however, provides specific, unambiguous, and quantifiable aspects that need to be measured, counted, or evaluated (e.g. "number of air conditioning units"). This way, the metric provides the measurement, quantifiable information to the indicator, and diverse metrics could be connected to only one indicator, as they provide different lenses through which to quantify progress towards one only adaptation-related goal.

"Scope" refers to the reference context of the proposed indicator. Indicators might be used to measure the progress of a specific measure (specific) or the plan as a whole (general). In the cases where the indicator is proposed for a specific measure, we also collect information regarding the "name of adaptation measure".

Whilst the focus of this paper is on adaptation, adaptation and mitigation are linked, with plans often combining adaptation and mitigation actions, or speaking about climate action in general. "Climate action domain" gathers information regarding the field of climate action that is being measured (mitigation, adaptation, general, or both). In cases of "mitigation" and "general" (i.e. general urban data being monitored as a reference for the evaluation, e.g. population), collected

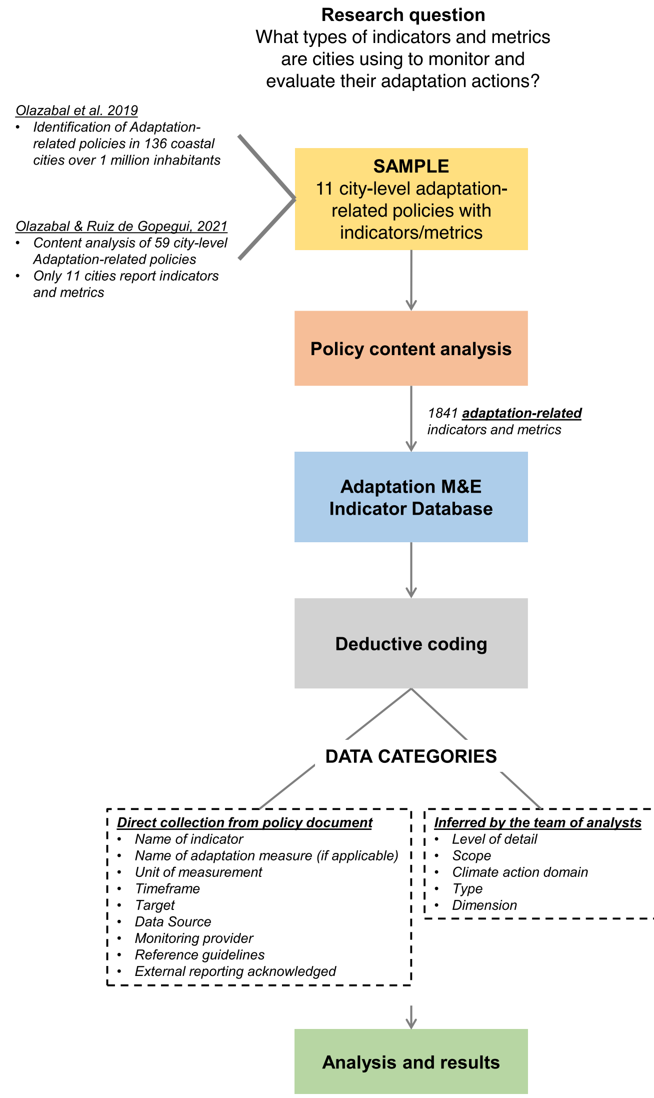

Fig. 1. Methodological approach followed in this study.

indicators have not been analysed further.

"Type" refers to the typology of the indicator used. Here we use the typology proposed by Hale et al. (2021) and Leiter et al (2019). This system proposes the classification of indicators into five categories: targets (express global targets of the adaptation action), inputs (capacity and resources), outputs (activities and products), outcomes (changes in behaviour), and impacts (changes in environmental, economic, and social indicators). While other indicator systems exist (see, e.g. Brooks, 2014), this category and its variations are widely used in the tracking of both urban-regional (Hale et al., 2021) and natural environment (Pearce-Higgins et al., 2022) adaptation. The strengths of this category are, for one, that it combines process and performance indicators, with input and output indicators relating to the process, while outcomes, impacts, and targets related to the performance. Moreover, the system allows for multiple periods to be assessed with output indicators referring to the short term, and outcome and impact indicators referring to the longer term.

"Dimension" refers to what aspects are being monitored. What is being monitored provides an insight into the picture the M&E framework is providing. Earlier studies (Feldmeyer et al., 2019; Salehi et al., 2019) have conducted analyses into the most prevalent dimensions across adaptation indicators. Five dimensions are most used: social, economic, environmental, infrastructure and governance. In this work, we limit ourselves to identifying the primary dimensions that the

Table 2
Data categories collected for each indicator and metric.

	Data category	Description / Examples
a	Name	Name of the indicator as in the planning document e.g. Shaded area.
b	Level of detail	Quantifiable degree of the proposed assessment tool in three levels: **Objective/Indicator/ Metric** (from less to more degree of detail).
c	Scope	The indicator/metric refers to the policy as a whole (**general**) or it is measure/goal-specific (**specific**).
d	Name of adaptation measure (if applicable)	Name of the specific measure or action the indicator is associated with.
e	Climate action domain	Provides information regarding the field (**Mitigation/Adaptation/ Both/ General**) to which the indicator or metric is contributing to.
f	Type	**Target, input, output, outcome, impact**. Only for adaptation-related metrics ('adaptation' and 'both', see row 'e').
g	Dimension	Domains of the elements that are being monitored/evaluated: **social**/human/society, **economic**/finance, **environmental**/natural, (built) **infrastructure**, **governance**/ institutional/political.
h	Unit of measurement	E.g. m^2
i	Timeframe	Frequency of measurement.
j	Target	A generally quantitative target that is aimed to be achieved and that will be monitored through the proposed indicator and metric.
k	Data Source	Source of the data required to feed the indicator/ metric. E.g. survey, database or on-site measurements.
l	Monitoring provider	Responsible for the M&E of the indicator.
m	Reference guidelines	National, regional or global guidelines, including international city networks, that the M&E system follows.
n	External reporting acknowledged	Bodies or organisations that will be reported typically to e.g. Regional governments, National governments, or International City Networks.

indicators are addressing. This analysis is helpful to broadly determine which domains are less addressed through indicators and thus, the adaptation dynamics that are potentially less understood.

Providing insights into the procedure of how these cities intend to monitor and evaluate their plans is critical. For that, "unit of measurement" further shows how these indicators are going to be measured, while "timeframe" shows the frequency of measurement. "Target" shows what the indicator's intended outputs, outcomes, or impacts are, expressed as quantifiable goals. "Data Source" refers to from where this data will be collected (e.g. existing database, data being monitored and provided by a different public authority).

Finally, "monitoring provider" refers to who oversees the monitoring and evaluation of each specific indicator, as normally they cover a wide range of topics and domains. This is also linked to the above categories in that it provides contextual information on how cities envisage the management of their M&E process. "Reference guidelines" refers to existing guidelines (developed by international bodies, national regulatory frameworks, or city networks, for example) being followed to identify indicators and define the M&E plan. "External reporting acknowledged" refers to the acknowledgement of bodies (regional, national, and city networks) to which information generated through collected data will be reported to.

Put together, these data points describe each city's M&E approach. We analyse the general trends for each data category, using, on one hand, general statistics and also, specific statistical methods and tools such as pivot tables to identify potential trends and cross-criteria relationships, and cluster analysis. We use the Kmodes algorithm to calculate the dissimilarities between data points and the Elbow Method to identify the optimum number of clusters.

3. Results

The results gathered in this section show the current state of practice of adaptation M&E systems and indicators in the 11 surveyed cities. The results of the study are presented deductively, with the general aspects related to the surveyed indicators presented first, followed by a more nuanced analysis of specific categories. The main results are summarized and highlighted in Fig. 2.

3.1. General aspects

In total, 1971 different indicators were collected from planning documents in the 11 cities, however, there was a significant variance between them. In terms of the 'climate action domain' covered, 130 out of 1971 of the proposed indicators were found not to be related to adaptation. This is applicable in planning reports that are broader in their scopes, such as joint mitigation and adaptation plans (Nagoya, Portland, and Barcelona), urban development plans (Auckland and New York City), resilience plans (Glasgow), or environmental plans (Tokyo). Of the 1841 adaptation-related indicators, 99.6 % were found to be designed to monitor the impact of specific actions or measures, while 0.4 % were associated with general policy goals.

Given the interrelation between adaptation and mitigation (Göpfert et al., 2020; Landauer et al., 2019; Sharifi, 2020, 2021; Ürge-Vorsatz et al., 2018), in cases where the indicator was directly or indirectly related to both types of climate actions, it was kept in the analysis. This was the case of indicators related, for example, to resources, air quality, or infrastructure improvements, that are generally associated with mitigation actions but that also lead to higher adaptive capacities (e.g., #304 *Number of people employed, salaried, and business owners and number of companies related to the green, social and circular economy* [Barcelona] or #342 *Integrated Transport system master buses in circulation* [Lima]). In total, 45 such cases were found throughout the 11 plans.

The total number of indicators associated with each plan and the percentage of adaptation-related ones are shown in Table 3. Higher percentages are correlated with climate-focused plans, either adaptation (Athens, Montreal, Lima, and Vancouver) or adaptation and mitigation plans (Barcelona, Nagoya, and Portland).

The number of proposed adaptation indicators in M&E plans (see Table 3) varies significantly, highlighting the different levels of granularity desired across city plans. At the high end of this variability is Montreal's adaptation plan which includes 1608 indicators related to adaptation. Conversely, only 2 indicators are proposed in Glasgow's plan, 3 in Auckland and 4 in Tokyo and Nagoya.

Montreal's indicators are defined per measure and district, with various measures being defined similarly for each district. While the M&E process developed in Montreal could be taken as an outlier, further analysis shows that this interpretation is misguided. Montreal presents similar characteristics to the other cities and plans, albeit with much higher absolute values, as illustrated in Fig. 2.

Despite containing measures affecting different city departments and involving complex data collection and evaluation processes, the survey shows that information related to the design and management of the M&E process (i.e. 'Monitoring provider', 'reference guidelines' and 'external reporting acknowledged') is never presented in any of these plans at the indicator level, but rather at a general level, if any (see Table 4). In addition, although all of them, except Nagoya, are members of international city networks that have developed M&E guidelines, e.g. C40 or GCoM, none of these plans acknowledges having followed any specific M&E guidelines developed by public or private entities at the international level or below.

3.2. Level of detail, type, and dimension of adaptation indicators and metrics

95 % of the indicators (see Fig. 2) are expressed as 'metrics' through

Fig. 2. Summary of main characteristics of adaptation indicators by city and plan: A. Level of detail; B. Type; C. Dimension; D. Unit of Measurement; E. Timeframe; and F. Target.

Table 3
Total number of indicators and proportion related to adaptation (i.e. categorised as Adaptation and Both, see Table 2) per city. Notes: Type: A/M (adaptation and mitigation), A (adaptation only), R (resilience), E (environment), D (Development).

Id	City	Total number of indicators	No. of adaptation-related indicators (%)	Type
1	Athens	81	81 (100 %)	A
2	Auckland	38	3 (8 %)	D
3	Barcelona	76	61 (80 %)	A/M
4	Glasgow	6	2 (33 %)	R
5	Lima	12	10 (83 %)	A
6	Montreal	1608	1608 (100 %)	A
7	Nagoya	8	4 (50 %)	A/M
8	New York City	69	21 (30 %)	D
9	Portland	33	27 (82 %)	A/M
10	Tokyo	20	4 (20 %)	E
11	Vancouver	20	20 (100 %)	A
	TOTAL	**1971**	**1841 (93 %)**	–

Table 4
General monitoring, evaluation and reporting data as reported in policy documents. Note: GCoM: Global Covenant of Mayors.

	Monitoring Provider	Reference Guidelines (Yes/No)	External reporting (Yes/No)	International city network memberships*
Athens	Yes, Municipality: Different departments	No	No	C40, GCoM & Resilient Cities Network
Auckland	No	No	No	C40 & GCoM
Barcelona	No	No	No	C40, GCoM & Resilient Cities Network
Glasgow	No	No	No	GCoM & Resilient Cities Network
Lima	Yes, Municipality: Department of Environmental Management	No	No	C40 & GCoM
Montreal	Yes, Municipality: Central Services	No	No	C40, GCoM & Resilient Cities Network
Nagoya	Yes, Municipality	No	No	None
NYC	No	No	No	C40, GCoM & Resilient Cities Network
Portland	Yes, Municipality	No	No	C40
Tokyo	Yes, Municipality	No	No	C40 & GCoM
Vancouver	No	No	No	C40, GCoM & Resilient Cities Network

Note: This information was collected either from the policy documents or the official websites of the international city networks.

specific and quantifiable aspects that can be evaluated. This generally speaks to good M&E practices in selected cities (Leiter & Pringle, 2018). Higher levels of detail are concentrated in cities such as Montreal (99 %), Barcelona (95 %), and Atenas (70 %). These cities also include larger numbers of adaptation indicators in their M&E plans. While Portland and Tokyo, with highly strategic plans, have 100 % objectives. These results indicate a correlation between plan level (strategic to action plan), the number of proposed indicators and the level of detail.

Corroborating existing literature (Olhoff et al., 2018), output indicators are the most popular across our sample, 96 % of the total, 72 % when excluding Montreal. Looking at specific city plans, output indicators dominate, with two exceptions: Auckland and Glasgow (see Fig. 2).

The abundance of output indicators is related to their relative methodological ease and practicality as compared to outcome or impact indicators. However, unless adaptation outcomes and impacts are credibly attributed and measured through output indicators, these can provide misleading information on the state of adaptation (Leiter & Pringle, 2018).

Outcome, input, impact, and target indicators combine for the remaining 4 % of indicators. Outcome indicators represent half of the remaining 4 % and are present in 8 out of the 11 plans. They are mostly reported in cities such as Athens (mostly concerning users and beneficiaries of adaptation interventions and environmental quality), Auckland, and New York City. Input indicators make up under 1 % of the total and are present in 3 cities (Athens, Barcelona, and Lima). The remaining percentage point is made up of target (here connected to indicators classified as 'general' in scope) and impact indicators, present in 3 and 6 plans, respectively (see Fig. 2).

In some city reports, the same outcome indicators are associated with different adaptation actions (see Fig. 3). For example, in Athens, the "relative decrease in local temperatures (surface and air), especially during the summer" is used to explain progress in terms of adaptation outcomes of different actions related to green roofs, parks, and blue corridors. Output indicators, on the other hand, are usually tailored for each specific action, and although their wording might be similar, they refer to different physical spaces, interventions, or communities (for example, in Montreal's adaptation plan).

Along with the type of indicator, another key feature is the indicator's dimension, i.e. domain being monitored. The overall results of the study show that the environmental domain (22 %, Table 5) is not overwhelming the other dimensions, as some studies suggest (Coger et al., 2021), while it is present in all 11 city plans (see Fig. 2). On the contrary, indicators referring to infrastructure and governance were found to be most prevalent among the plans. Infrastructure indicators made up 23 % of the total and were found in 10 out of 11 cities. Governance indicators were the most abundant, representing 48 % of the total, despite only appearing in 6 cities.

3.3. Units of measurement, targets, and timeframes for data collection

When it comes to establishing evaluation methods as part of the M&E plan for each indicator, there is a general lack of definition (see Fig. 2). Only 19 % of the indicators have an associated target and, overall, only 5 out of 11 cities include targets for their indicators. The practice is more widespread in cities like Athens, Nagoya, and New York City, where there are targets for each one of the proposed. However, different practices are found. In New York City, for example, targets are associated with each specific indicator (for example, "percentage of New Yorkers living within a walking distance of a park", the target being 85 % by 2030). Meanwhile, in Athens, the target is associated with the action. For example, "ACTION 3: Strengthening greenery in the renovation of public spaces (Code: AMP 3)" in the Climate Action Plan of Athens has 4 associated indicators ("Area of new planting areas", "Number of studies", "Number of projects implemented" and "Improvement of urban landscape") but a common target "Greening

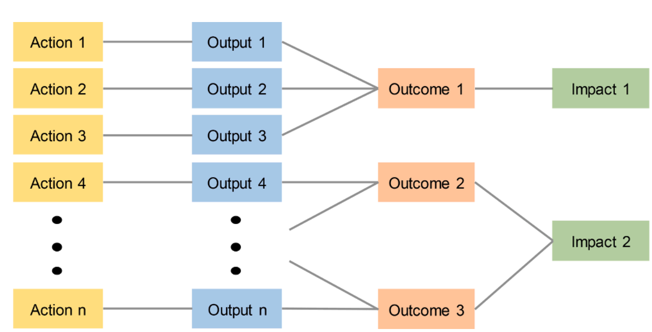

Fig. 3. Illustration of the links between actions, outputs, outcomes, and impacts.

Table 5
Results of the cluster analysis showing groups of indicators with similar characteristics.

	Level of detail	Type	Dimension	Unit of Measurement	Timeframe	Number of indicators grouped (%)
Cluster 1	Metric	Output	Environmental	Yes	No	510 (28 %)
Cluster 2	Metric	Output	Governance	No	No	578 (31 %)
Cluster 3	Metric	Output	Infrastructure	Yes	No	372 (20 %)
Cluster 4	Metric	Output	Governance	Yes	No	381 (21 %)

increase by at least 10 %".

Having a target, however, is not directly reflected in the definition of clear units of measurement. 40 % of indicators with targets do not have an associated unit of measurement. This is generally the case for indicators with targets associated with actions, such as Athens. In general, output indicators are more likely to have associated units of measurement, with a total of 64 % of indicators including units of measurement.

Timeframes are established across 6 out of the 11 cities (Auckland, Barcelona, Glasgow, Lima, New York City, and Vancouver), however, overall, the indicators associated with these monitoring processes only make up 6 % of the total. Not establishing a timeframe is not a synonym for not having a general reporting period. For example, Montreal does not establish a timeframe to monitor each indicator, but it does establish a reporting calendar for the whole plan. Tokyo vaguely mentions reporting, simply referring to regular monitoring, without specific timelines. There is heterogeneity between indicator timeframes too, out of the 6 cities, only Lima established a specific monitoring period for each indicator. Conversely, Barcelona or New York establish a common timeframe for all indicators. Regarding the sources of data used to monitor indicators, 99 % of indicators do not include information on from where data will be collected. Only Glasgow, Lima, Nagoya, and Vancouver inform about some data sources to monitor certain indicators. They direct to existing databases (e.g. census), other public authorities, or existing planning instruments, such as Vancouver's "Health City Strategy" to collect information about the "Number of summer days annually with a special weather statement (heat-related) or heat alert".

3.4. Cluster analysis

Table 5 below shows the results of the cluster analysis applied to the 1841 adaptation-related metrics. The analysis identifies the four most common approaches to evaluation in this sample. Echoing the previous findings, all clusters coincide in that they are made up in their majority by metrics looking at outputs with no timeframe. Cluster 1 has a majority of environmental metrics which include units of measurement. Cluster 2 and Cluster 4 look both generally to the governance dimension, but only Cluster 4 commonly contains metrics with allocated units of measurement. Cluster 3 is mostly made up of infrastructure metrics with units of measurement.

4. Discussion: Present trends and future perspectives

4.1. Overall patterns

In our study, overall, we found that specific dimensions are strongly connected to indicator types. Although the cluster analysis provides four groups with similar characteristics taking a larger number of data categories into account (namely, level of detail, type, dimension, unit of measurement, and timeframe), a nuanced look into the data provides more interesting information describing areas where the maturity of the evaluation approaches might be more advanced. For example, 72 % of all output indicators identified correspond to either the governance or infrastructure dimension, while only 14 % of outcome indicators are connected to these domains. Generally, governance and infrastructure domains indicate the progress being made in the implementation of projects, adoption of plans, events held, executed infrastructure interventions, etc., all related to the assessment of implemented actions (outputs). A full breakdown of the type and dimension correspondence can be found in Table 6.

In contrast to infrastructure and governance, social and economic domains are left at a margin, being reflected in only 5 % and 1 % of the total number of indicators. Social indicators were present across 9 city plans, while economic ones were only found in 5.

Social and economic indicators are more prevalent among outcome and impact indicators. Around 50 % of all outcome and impact indicators are either economic or social in dimension, while only representing 6 % of all output indicators. Outcomes of social and economic domains are normally related to usability, users, damages prevented, or revenues. Impact indicators, on the other hand, are mainly related to effects on the well-being and health of communities and ecosystems. Input indicators are related to the governance dimension, typically indicating resources being allocated to adaptation decision processes, such as the number of participating entities or individuals.

The Output/Input (Infrastructure/Governance) and Outcome/Impact (Social/Economic) links identified are hypothesized to be down to time, along with direct municipal control. Improvements and changes to infrastructure or governance are shorter-term than social or economic changes, meaning that shorter-term indicators are required to measure activities related to these domains, i.e. output or input indicators. On the other hand, social and economic changes and dynamics tend to happen and be reflected in the longer term, and as such require indicators with a longer-term perspective for them to be adequately monitored, i.e., outcome or impact indicators. However, while time is a factor, the main explanation might be related to municipal control. Governance and infrastructure are elements over which local governments have direct control and can act on. Control over the social and economic domains is complex, given the influence of external factors. As a result, these are used to gauge the effects that adaptation activities have, requiring outcome indicators. Examples of this are '*Number of cool points built into application*' (output - infrastructure) or '*Number of users* (based on app downloads)' (outcome – social) (Athens). This might also be why, in general, the level of detail achieved in the definition of the indicator is higher in outputs (metrics represent 97 %) and inputs (metrics represent 86 %), rather than for outcomes (42 %) or impacts (25 %). The shorter the timeline and stronger the control, the easier it is to find adequate evaluation means.

The environmental dimension relates mainly to outputs and

Table 6
Dimensions addressed by the different types of indicators in % and number.

	Envir. % (no.)	Govern. % (no.)	Infrastr. % (no.)	Social % (no.)	Econ. % (no.)	Total % (no.)
Input	0 % (0)	**100 % (7)**	0 % (0)	0 % (0)	0 % (0)	**0.4 % (7)**
Output	22 % (391)	**49 % (877)**	23 % (416)	5 % (73)	1 % (17)	**96 % (1774)**
Outcome	37 % (13)	5 % (3)	9 % (4)	**44 % (17)**	5 % (3)	**2 % (40)**
Impact	25 % (3)	0 % (0)	17 % (2)	**50 % (6)**	8 % (1)	**0.7 % (12)**
Target	**62.5 % (5)**	12.5 % (1)	0 % (0)	25 % (2)	0 % (0)	**0.4 % (8)**
Total	**22 % (412)**	**48 % (888)**	**23 % (422)**	**5 % (98)**	**1 % (21)**	**100 % (1841)**

outcomes. Environmental output indicators generally refer to results such as the number of green and blue infrastructure projects delivered or resources saved. Environmental outcome indicators refer to ecosystem services gained or maintained or, in general, environmental dynamics as a result of specific actions. The environmental domain (i.e. the environmental quality of a city) is also important in target indicators. These indicators (8 out of 1841 adaptation indicators) have been connected in our study with those indicators labelled as 'general' in scope, i.e. that do not refer to specific measures of actions but rather to the whole plan. Five of these are explanatory and progress indicators that help to understand the reference baseline (e.g. number of heatwave days) and the general progress of action implementation (as in Vancouver's adaptation plan). The 3 remaining indicators assess population resilience and vulnerability or ecosystem quality. It is for this reason that target indicators are strongly connected to impact indicators. They both should refer back to the general goals of the adaptation plan. However, none of these proposed target indicators has been assigned a quantifiable target, thus not complying with Hale et al. (2021)'s framework.

Based on this, we concur with both Coger et al (2021) and Leiter and Pringle (2018) and add that M&E frameworks and indicators imperatively need to cover a wide range of dimensions, from environmental to socio-economic as well as governance and infrastructure dimensions. By doing so, given the link between type and dimension, the potential pitfalls of output-intensive monitoring processes may be mitigated, as, by reinforcing the presence of environmental, social, and economic indicators, these frameworks will automatically include an increased amount of outcome indicators, moving away from the 'output myopia'.

As referenced in the section above, the lack of process definition is another general trend identified across the sample cities. In general, a lack of information regarding the evaluation system can lead to considerable methodological problems resulting in, at least, inefficient monitoring systems, with overlapping responsibilities and use of different units, and, at worst, ineffective systems, where the M&E process is not feasible or does not inform properly.

Apart from these patterns, no other general trend has been identified across the sample. Counterintuitively, this lack of trends is a trend in and of itself given that this variability in approach shows the different ways cities conceptualize and prioritize adaptation and highlights the lack of unique lenses for adaptation evaluation. What is monitored and evaluated seems to be rooted in the local context in which the M&E framework is designed. However, how it is monitored need not be. As previously discussed, all but one (Nagoya) of the cities are members of the C40 Network, the 100 Resilient Cities Network, or the Global Covenant of Mayors. While trying to standardize what is to be measured may not respond to local ideas or needs, the standardization of the methodological process of how to monitor may lead cities to increase their capacity and have more efficient and effective ways of measuring their interpretation of adaptation.

4.2. *A look forward: Policy recommendations*

The results of this investigation have shown an overwhelming majority of output indicators included in city adaptation plans, a fact that at least in part has contributed to the prioritization of some dimensions, with governance and infrastructure indicators in the majority. Furthermore, this study has also shown that there are significant information gaps when it comes to methodological information regarding these indicators. The final distinguishable point is a lack of any clear trends, outside of output abundance and lack of information, a trait argued to be caused by an apparent disconnection between local adaptation planning and external guidance.

Measuring and evaluating adaptation is a complex challenge. Based on the information collected in this study, we argue that more directions are required to conceptualize adaptation indicators and their evaluation processes. We base this argument on the disproportionate focus on output measurements rather than on outcomes or impacts. In particular, we argue that the process of decision-making in adaptation should facilitate the identification of appropriate indicators and may help in trespassing the 'output myopia'. There are examples of the deficits encountered in adaptation decision-making that might be at the heart of this problem. Earlier large-scale studies analyzing the state and needs for adaptation policy-making worldwide (Olazabal et al., 2019b), found, in a sample of 226 adaptation policies, that risk and vulnerability assessments are rarely connected with adaptation decision-making, i.e. decisions regarding adaptation measures were not using information derived from diagnoses of risks and vulnerabilities, at least as documented in government reports. This has direct consequences on monitoring and evaluation plans, as, although the goals are clear, there is a general lack of knowledge regarding whether and how specific measures increase the capacity to adapt or reduce risks to populations, infrastructures, or ecosystems, and in which measure. As a result, monitoring and evaluating outcomes and impacts of adaptation measures, interventions, or projects, becomes a challenge. This also explains why, more recent studies synthesizing contents of adaptation policies at the city scale have found a lack of efforts directed toward the prioritization of adaptation options during plan creation (Olazabal & Ruiz De Gopegui, 2021). These stages of adaptation decision-making are critical to identifying decision criteria and then using these in the evaluation of adaptation outcomes and impacts.

Based on the above, we argue that a better and more robustly designed adaptation policy and/or planning process would facilitate the preliminary identification of useful and usable tools and resources for adaptation evaluation, including adaptation objectives, indicators, and metrics. Fig. 4 below, shows how the identification of indicators that measure inputs, outputs, outcomes, and impacts should be linked back to the rationale of the adaptation decision-making process. In the absence of this rationale, likely, identified adaptation indicators won't provide the information required to make decisions that enable improvements in urban climate adaptation management and policy-making (see dashed arrows in Fig. 4).

On the other hand, and with exceptions in Vancouver and New York City, we found a general lack of attention towards the monitoring of socio-economic and environmental explanatory variables and climate dynamics. This set of indicators, which are not directly connected to specific adaptation measures but rather, to the variables that have helped to diagnose risks and vulnerabilities to specific climate hazards, are critical for the observation of changes in climate baselines and the understanding of progress, the absence of it or the emergence of maladaptive responses. We recommend that M&E plans include a set of baseline indicators to this end.

Better guidelines could come from international and regional city networks but also national and regional/state governments. This study is limited by a specific focus on local policies but future research should also focus on the connections between state-level (and/or national-level) and local climate monitoring and evaluation policies. Heidrich et al. (2016) for example, concluded that there is a strong link between the existence of European national policy and/or national obligation to develop local plans, and the existence of local plans themselves. However, the connection between the quality of plans or the M&E integrated into them and the guidance or recommendation by national regulation on how to do this has not been covered yet in current scientific literature, neither in theory nor in practice.

5. Conclusions

While the practice of establishing adaptation indicators and metrics is still a challenge, there is a general recognition of its importance for the global progress assessment of adaptation (Magnan, 2016). A few proposals have been put on the table, based on current collections of indicators and expert knowledge (Feldmeyer et al., 2019), published literature (Arnott et al., 2016; Hale et al., 2021), or lessons from specific city cases (Solecki & Rosenzweig, 2020). In this study, we have added to

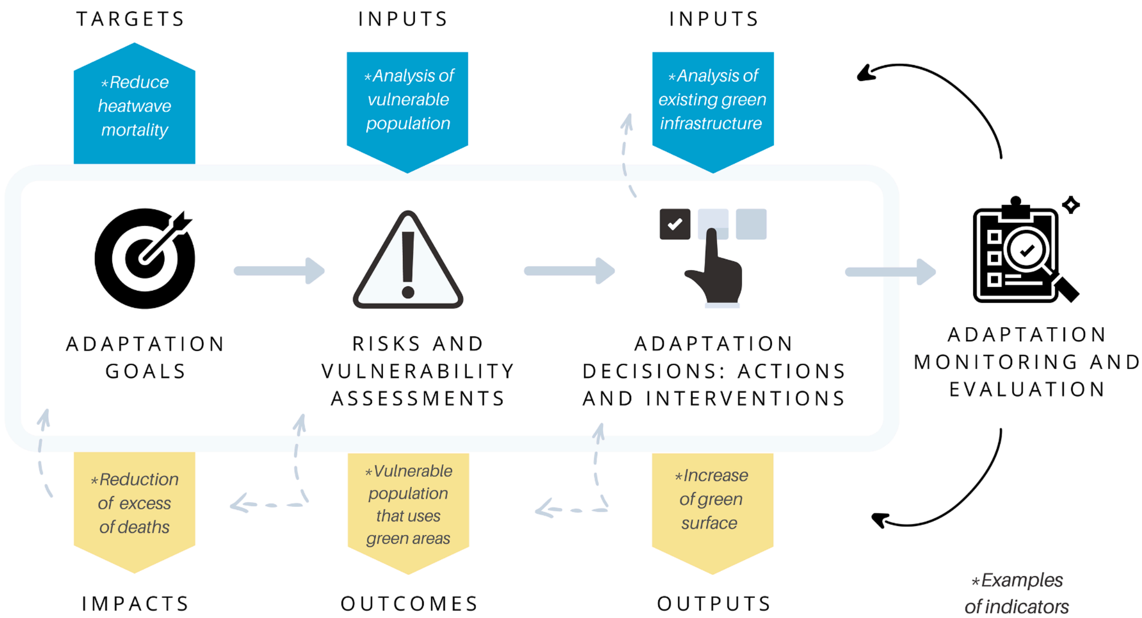

Fig. 4. Adaptation indicators and metrics (measuring inputs, outputs, outcomes, and impacts) should be connected to adaptation decision-making criteria, processes, and stages.

this literature by analysing and discussing the state of practice of M&E and associated indicators in current local adaptation policy and planning documents.

We collect and analyse adaptation indicators and metrics from a sample of 59 city adaptation-related plans. Adaptation indicators were available in only 11 of these local government reports, which reflects the global embryonic stage of adaptation metrics practice. Collected from these plans, we code 1841 adaptation-related indicators and report information regarding M&E management. The results show that, significantly, an important share of indicators focuses on outputs, while outcomes and impacts, and, generally, the social and economic dimensions remain largely unaddressed. The lack of information regarding M&E system specifications such as targets, units of measurement and data sources is also remarkable. Because reductions of climate change vulnerabilities and resilience increases (which are generally the observable evidence for adaptation goals) can only be measured through outcomes or impacts, a dominant focus on outputs means that policies are far from connecting actions to goals, and thus, far from being able to measure progress on successful or effective adaptation. We conclude that future practice should allocate further efforts to a more effective design of the planning process of adaptation aiming to connect adaptation goals to their associated measures. This will potentially facilitate the identification of relevant tools (e.g. indicators and metrics) for monitoring, evaluation, reporting and learning by setting, already during plan creation, relevant aspects that will inform about the effectiveness of measures towards goal consecution.

The dataset we have made available with this paper serves as a first reference baseline of local adaptation indicators and metrics planning practice. We hope that it will fuel further studies that explore contextual factors and usability of M&E frameworks, as well as prospective studies that take stock of current initiatives to reflect on feasible higher-level adaptation stocktake mechanisms. It may also be used by the scholarly community to categorise metrics by looking at other different domains and questions, such as, for example, aspects of justice and equity arising from these proposals.

In current practice, experimenting and innovation in local adaptation planning and policy are observed. Currently, various of these cities have moved to other indicator systems or even different M&E approaches (Lewis & Olazabal, 2021). We see this as an adaptive management process where cities are learning from their own experiences and testing and innovating new approaches.

Adaptation to climate change is a recently acknowledged societal challenge and society is just starting to understand the complexity of managing processes to adapt. Conceptual understandings of adaptation success and currently established adaptation goals across any level of policy-making are generally ambiguous, this results in a lack of agreed methodologies to understand and evaluate its progress which adds to the difficulty in verifying the effectiveness of adaptation actions. Considering the challenge ahead, i.e., adaptation not being something that can be achieved in the short-term but a long-term continuous process, adaptation actors and decision-makers need to understand the importance of connecting planning with evaluation and learning processes. As we are witnessing an end to a wave of first-generation adaptation plans, learning how to learn will be key during this decade.

6. Data availability statement

The adaptation indicators *dataset* produced for this study can be accessed at https://doi.org/10.5281/zenodo.5705687 and it is free to download and use.

CRediT authorship contribution statement

Sascha M. Goonesekera: Formal analysis, Investigation, Writing – original draft, Writing – review & editing, Visualization. **Marta Olazabal:** Conceptualization, Methodology, Formal analysis, Investigation, Writing – original draft, Writing – review & editing, Visualization, Supervision, Project administration, Funding acquisition.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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